Catch the Ghost: Neutrino Diffuse Search by RNO-G

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What is a Neutrino?

Neutrino is a weakly interacting particle that can only interact via gravity and weak force. Neutrinos have very low mass: electron neutrinos only have mass lower than 8.5×10^{-10} times a H^1 *nucleus.*

Weak force governs most of nuclear decay processes. The reaction is rare. Low energy neutrinos(like solar neutrinos) can go through the Earth non-interacting and unimpeded.

Because of this nature, neutrino plays an essential role on multi-massager astrophysics to obtain information directly from the source.

Sources of neutrinos:

Neutrinos are popular byproducts of nuclear reactions and short-lived CR (cosmic ray) decay.

The observed neutrinos originate from stellar objects like our Sun, supernovae, and galactic centers (AGN), and other cosmic rays.

Flux of neutrino from different source

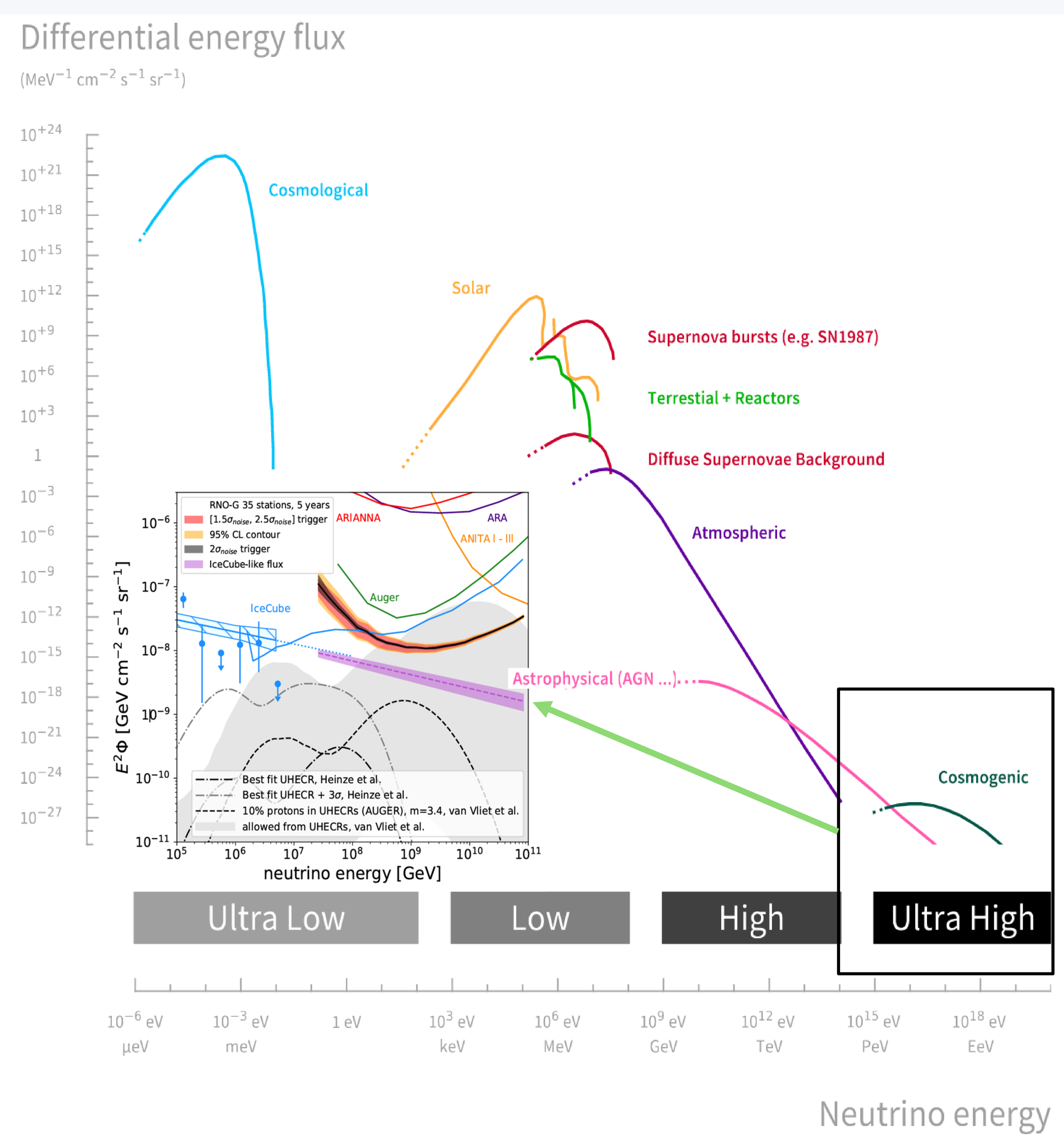

Figure 1 Large graph: observed energy range vs the flux of different dominate cosmic neutrino sources[1]. Left bottom: The five-year sensitivity (90% CL upper limits) of RNO-G to the all-flavor diffuse flux for 35 stations (assuming the stations are active two thirds of the total time), compared with existing experiments and several predicted fluxes in Ultra high energy region.[2]

Where to catch neutrino:

Neutrinos only interact when in close contact with other particles. In addition, the UHEN are very rare. Thus the detector needs to cover a large area and be surrounded by clear dense matter for neutrinos to interact.

To satisfy the requirement with reasonable budget, with more than 3km thick clear packed ice, polar regions are chosen for most popular choice for UHEN experiment.

Detection of Neutrino, RNO-G

RNO-G(Radio Neutrino Observatory in Greenland) is a in-ice UHEN(Ultra High Energy Neutrino) detector in Arctic region.

It consists of a total of 35 planned stations, each station includes 24 antennas ranged from surface level LPDA to 100m under ice forming a phased array. By design, the 35 stations form a grid with inter-station distance 1.25 km. As of the current date, 8/35 stations are deployed and in operation.

RNO-G station information and deployment

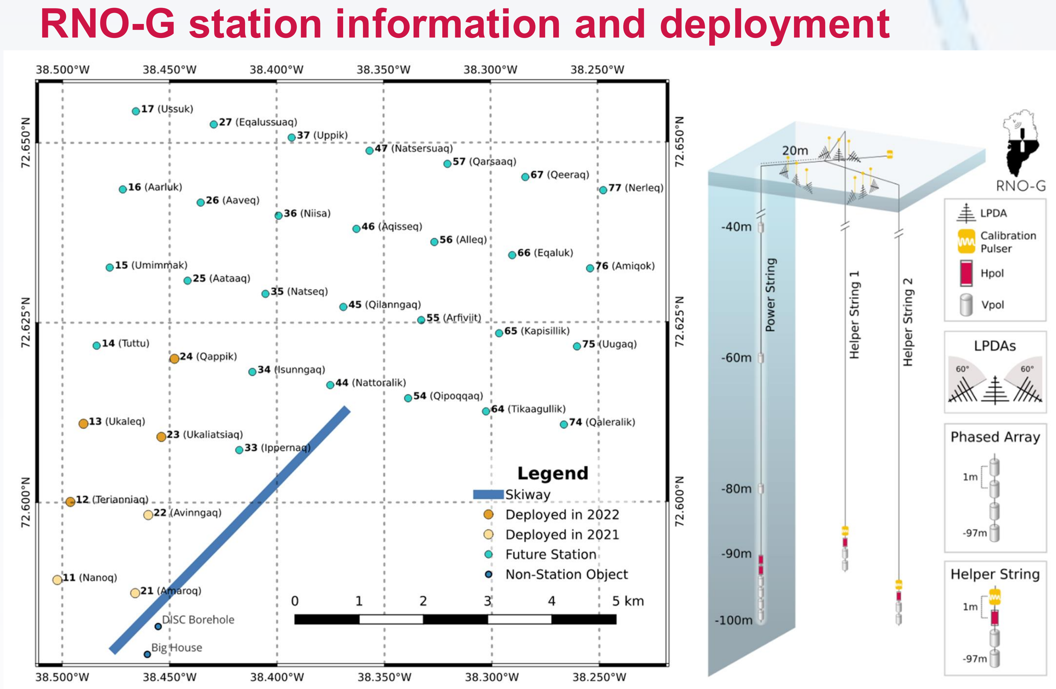

Figure 2 Left: Planned and existing layout of the 35 station array of RNO-G.Depolying process by the end of year 2022. The main building of Summit Station is labeled Big House. Right: The station construction as installed for the first seven stations of RNO-G, showing the three instrumented boreholes down to 100 m, as well as the antennas in shallow trenches near the surface.[2]

Neutrino Detection Mechanism

When UHE particles interact in ice, they will produce cone-shaped radio-wave showers, this process is called **Askaryan Radiation**.

Whenever the radio signals produced by neutrinos hit the phased array, based on the information on arrival time, magnitude, polarity and spectrum, we can reconstruct the key properties of the original neutrinos.

Example of events signal hit detector

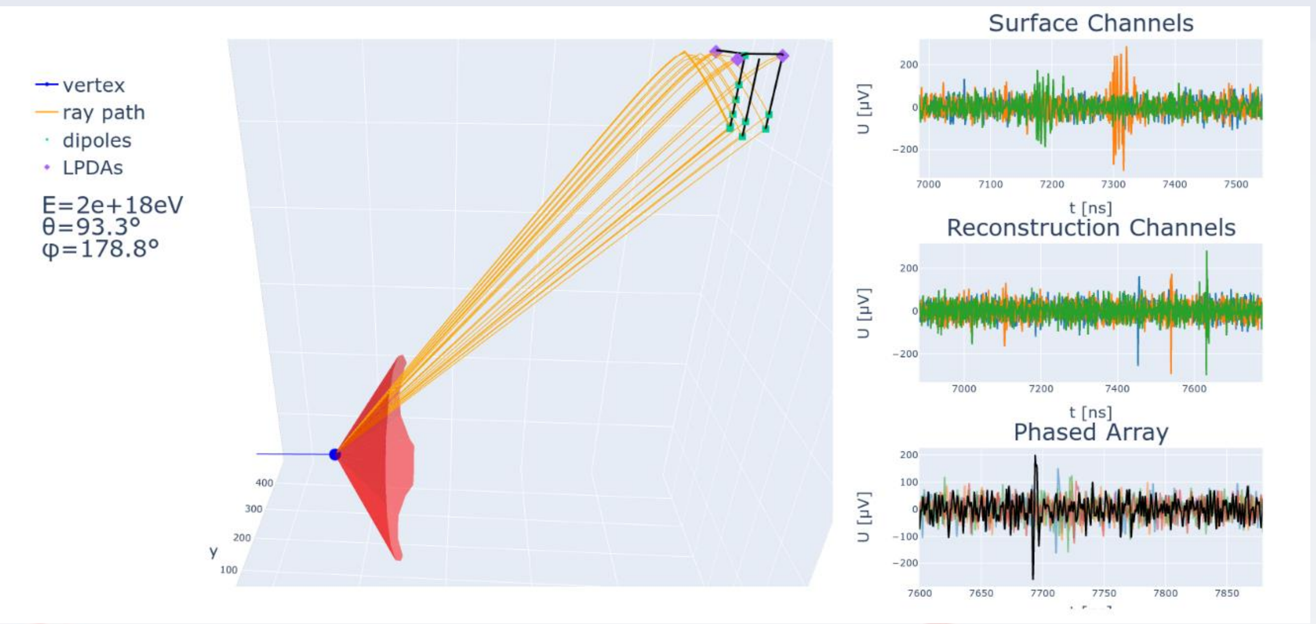

Figure 3, A simulated RNO-G neutrino event. The left side shows the event geometry illustrating both the direct and reflected ray-paths to the antennas, as well as the incoming neutrino and interaction vertex (blue) and its Cherenkov cone (red), where the strongest signals are expected. The right side shows the waveforms in selected antennas.[3]

Diffuse search

Diffuse search means to **search the whole visible sky range of the detector** without any preset source direction.

For the RNO-G diffuse search, it is planned to be conducted by training a supervised machine learning algorithm called linear discriminant analysis (LDA) to separate neutrino events from the noise events.

The algorithm is trained on simulated neutrino data and a small portion of station data after filtering and cleaning. When the training reaches a certain accuracy on another small set of the test data, it will be applied to all RNO-G data to output possible neutrino candidates for further detailed analysis.

RNO-G diffuse search flow chart

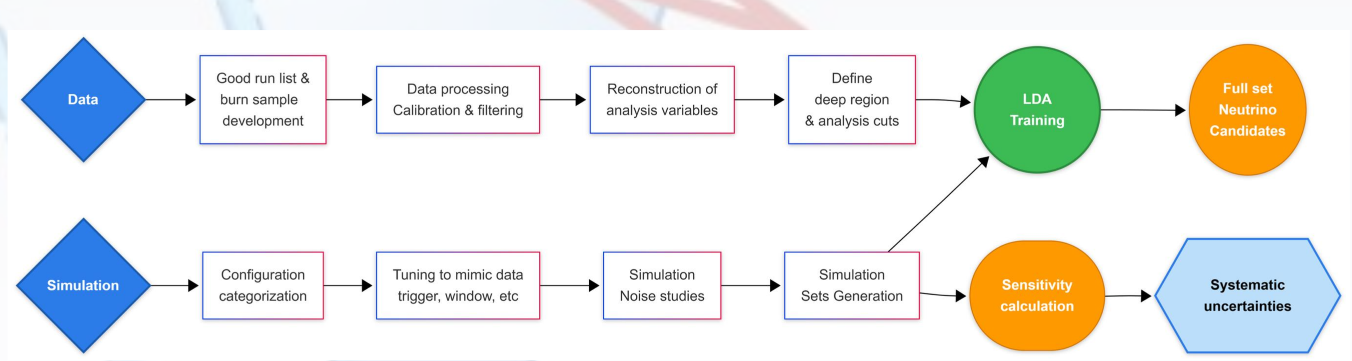

Figure 4, the RNO-G diffuse search flow chart. It separate the process into two main route Data and Simulation(marked by blue diamond node). The main output of the search is marked by orange oval. LDA training marked one of the key midpoint of the search which marked with green circle. And systematic uncertainties marked by light blue.

In terms of simulation, the sensitivity for the whole experiment with given search time is calculated. The sensitivity is a key physics property to pinpoint the neutrino flux (like in figure 1 bottom left) and gives us insight about the source process of this mysterious particle whether that's the center of the galaxy or ancient particle debris originated from the early universe.

RNO-G configurations by station uptime

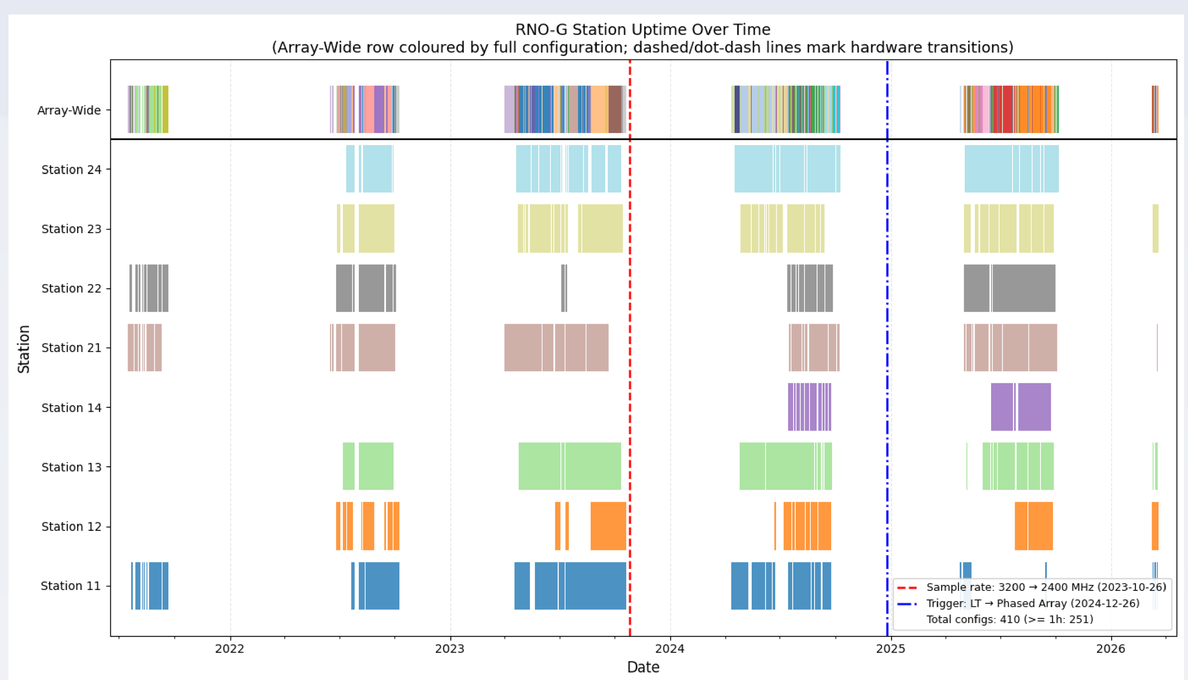

Figure 5. RNO-G configuration categorization with individual station uptime. The red and Blue vertical line indicate the major hardware change that will cause a configuration change. The overall 410 kinds of configuration is shown at the top array-wide row using different colors

RNO-G is an evolving project, every year the collaboration discusses possible improvement based on past data. The figure above shows RNO-G configurations based on station uptime combinations and important hardware implementations.

Currently, the diffuse search simulation is working on replicating some features specific to the actual data like jittering of the data.

Data replication example: trigger jittering

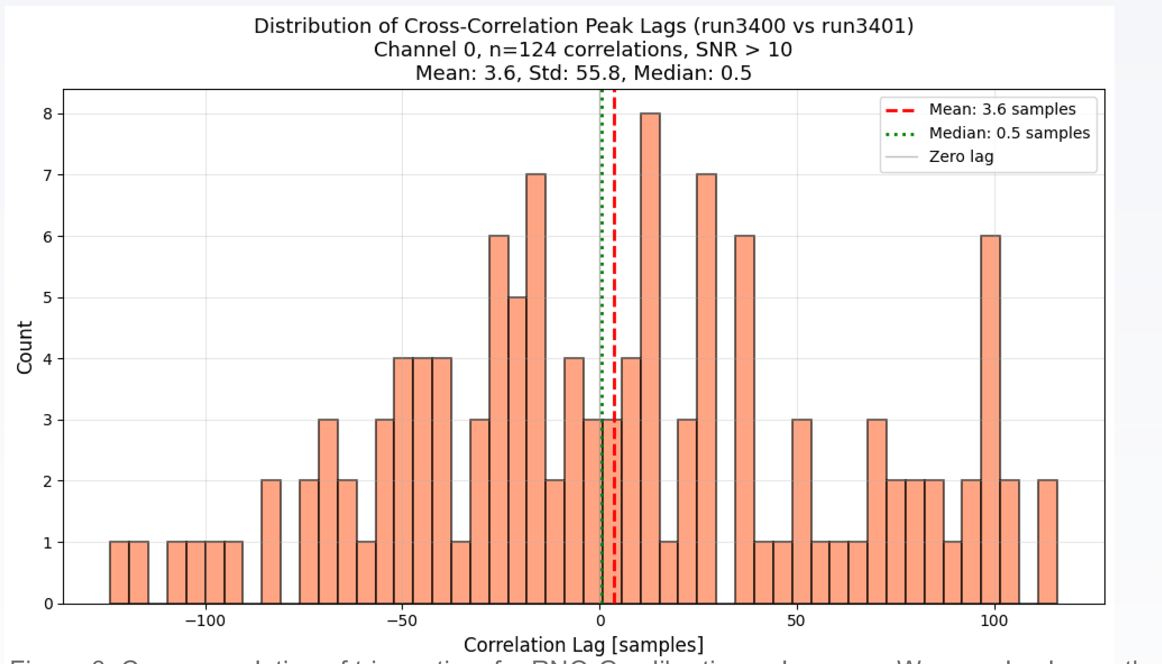

Figure 6. Cross correlation of trigger time for RNO-G calibration pulser runs. We can clearly see the data formed a triangle shape. Indicate the data have a uniform distribution +-64 sample. This is caused by the sample block only goes to readout once it fully complete the block, where the trigger pulse can arrive anytime in the sample block.

REFERENCES

1. B. Oeyen, D. Ryckbosch, and J. Stachurska, "An empirical ice model for the Radio Neutrino Observatory in Greenland (RNO-G)," Mar. 2025, doi: 10.5281/zenodo.15067985.
2. S. Agarwal *et al.*, "Instrument design and performance of the first seven stations of RNO-G," Feb. 11, 2025, *arXiv*: arXiv:2411.12922. doi: 10.48550/arXiv.2411.12922.
3. J. A. Aguilar *et al.*, "Design and Sensitivity of the Radio Neutrino Observatory in Greenland (RNO-G)," *J. Inst.*, vol. 16, no. 03, p. P03025, Mar. 2021, doi: 10.1088/1748-0221/16/03/P03025.

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background picture from ref 3

*** Research in Progress, for newest results check: https://radio.uchicago.edu/wiki/index.php/Conference_Talks**